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ORIGINAL PAPER

Biomass production of herb species in broad leaf forests in Kumaun Himalaya, India

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Abstract: The study focuses on the dynamics and biomass production ($g \cdot m^{-2}$) of understory (herbaceous) plant community under broad-leaf forests consisting of *Quercus leucotrichophora* (Banj-oak), *Quercus floribunda* (Tilonj-oak) and *Quercus semicarpifolia* (Kharsu-oak), respectively in central Himalaya, India. With increasing altitudes, the density and biomass decreased significantly across the three types of forests. Banj-oak forest harboured the maximum density and biomass among the other sampling sites. The mean density of herb species in two contrasting orientation differed significantly ($p<0.05$), showing relatively higher density on slope orientation (west). Across the sites, total production declined significantly with increasing altitude of the sites ($p<0.05$), and Banj-oak forest presented the highest production.

Keywords: orientation; altitude; forest type; species composition; density; biomass

Introduction

Climate change and increasing atmospheric carbon dioxide (CO_2) concentration are expected to have significant effect on ecosystems, but the magnitude of the response may vary strongly across the complex consequences (Riedo et al. 2001). The patterns of net primary productivity (NPP) at regional and global level and their determinants have been long interestingly parameters for ecologists (Leith 1975; Knapp and Smith 2001). Net primary productivity (NPP) is generally defined as the net assimilation of atmospheric CO_2 into organic matter, which is a key marker for the ecosystem management or an important component for terrestrial carbon cycle.

Basically, NPP is driven by solar radiation and can be constrained by light, precipitation and temperature (Field et al. 1995). In addition, Mutanga et al. (2004) reported that at landscape scale, topographic factors such as slope, aspect and altitude together with soil characteristics influence the biomass production. Earlier, Davigneaud (1968) concluded that a well balanced natural plant community, regardless of species composition, should have a similar dry matter production, net primary productivity and biomass accumulation under similar conditions. In the mountains, there are few favorable micro-sites for plants to establish through development of specific adaptive traits as the elevation increases. Therefore, the effects caused by elevation changes could also account for the decline of species richness of spermatophyte (plant species richness), (Korner 2000).

Brown (2001) stated that elevation gradients could create the varied climatic conditions along with resultant soil differentiation and promote the diversification of plant species. Mark et al. (2000) found that topographic features (elevation, exposure and slope) were responsible for the macro-scale patterns of alpine vegetation distribution on Mount Armstrong in New Zealand. Moreover, Criddle et al. (2003) elaborated their view that the regional pattern of species richness had been a consequence of many interacting factors and plant productivity.

Herbaceous flora constitutes only a small proportion of the total biomass in the forest ecosystem and plays an important role in ecological characteristics (Whittaker 1966) and dynamic layer for forest stratum (Gilliam and Christensen 1986). Productivity and nutrient relationship of these plants often indicate the soil fertility (Gilliam 1988), which possibly depends on the elevation gradient including slope, orientation and climatic regime (Perez-Corona et al. 1998). Moore and Allen (1999) defined that the quantification of understory vegetation is important for understanding the forest dynamics because it influences on nutrient cycling and energy flow layer, which may also provide a clue

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regarding to the resources availability (Scheller and Mlandenoff 2002).

The Kumaun hills of Central Himalaya extended for about 300 km from the north-west to the south-east along a part of western Nepal. It lies within the phytogeographical transition of two distinct Himalaya realms; the wet eastern and dry western Himalaya. Thus this region is usually treated as a distinct zone, the Central Himalaya. The mid-altitudes (1 500–3 300 m a.s.l.) region of Kumaun Himalaya covered with extensive Himalayan moist temperate forests (Champion and Seth 1968) with different oak species forming climax vegetation. The vegetation of this region deserves much attention due to its particular position in the vegetation patterns of entire Himalaya.

The aim of this study was to analyze the above-ground biomass, below-ground biomass and net production of the herbaceous flora to understand morphological data, species richness and soil resources to control the pattern of herbaceous growth under different woody canopies at different elevation gradients.

Material and methods

Study area

The study area is located from 1 980–2 600 m a.s.l. (between 29°22'–29°23' N latitude and 79°26'–79°28' E longitude) in Nainital, Kumaun Himalaya. There were three forests in Kumaun Himalaya, i.e., Banj oak forest (*Quercus leucotrichophora*) situated at 1 980 m a.s.l., Tilonj oak forest (*Quercus floribunda*) located at 2 300 m a.s.l. and Kharsu oak forest (*Quercus semecarpifolia*) located at 2 600 m a.s.l. The climate is the temperate monsoon areas, snowfall being frequent during winter months (Dec–Feb). The annual precipitation in the study area is 2 488 mm and about 80% of the precipitation occurs from mid- June to mid September. The average maximum temperature ranged from 13.9°C from February to 23.7°C in April and the minimum from 4.9°C in February to 16.5°C in July. The rocks of the study area belong to Krol series (Valdia 1980). Soil texture was sandy clay and it was acidic in nature (pH 4.7 to 7.0). The organic carbon and total nitrogen in soil (up to 30 cm soil depth) were 2.1% and 3.2% as well as 0.2% and 0.3% respectively (Singh and Singh 1987).

Sampling and calculations

In order to analyze the phytosociology of the herb layer along each forest site, 15 quadrats of 1 m × 1 m in size were set and placed randomly and field data were analyzed for frequency, density and abundance (Curtis and McIntosh 1950). Moreover, at each forest site three sub-sites were divided, including hill base, hill slope and hill top. At each sub-site, 15 quadrats (1m ×1m) were placed randomly to assess the above and below-ground biomass. The below-ground biomass was harvested from each monolith (25 cm×25 cm×30 cm) from each quadrat on sampling date after the above-ground components had been sampled and calculated by following Kuramoto and Bliss (1970). The different parts of plant material in the laboratory were dried at 80ºC. The peak biomass was harvested in September. Above-ground net production (ANPP) and below-ground net production (BNPP) were calculated by biomass losses during the growth period (Swamy and Ramakrishnan 1987).

Data analysis

Data analysis was carried out by following Snedecor and Cochran (1967) to test for significant differences between different parameters. Comparison of different substrate components was conducted using a Generalized Linear model (GLM), comprising a binomial family with a logit link function by using an open source system, R version 2.10.0 (http://www.r-project.org).

Results and discussion

Density of herb layer in the present study in Banj-oak, Tilonj-oak and Kharsu-oak forests varied from 15.8 to 40.9, 9.0 to 26.4 and 9.1 to 12.3 individual·m^{-2}, respectively. Maximum density occurred at the Banj-oak forest and minimum occurred at the Kharsu-oak forest. Across the aspects, Banj-oak forest contained the maximum density. Between the stands, the density at the hill slope was higher than others. The distribution of herb species differs between sites and stands (Table 1). The mean density (34.7 individual·m^{-2}) and biomass (8.8 to 80.4 g·m^{-2}) on the western slope were significantly higher than that on other orientation slopes (Table 1 and 2).

Table 1. Distribution pattern of species in sub-sites of different forests

Forest /Site	Orientation	Sub-site density (individual·m^{-2})			Mean
		Hill base	Hill slope	Hill top.	
Banj-oak	East	22.9	22.3	15.8	20.3
(1980 m a.s.l)	West	42.9	40.9	20.2	34.7
Tilonj-oak	East	22.1	24	9	18.4
(2300 m a.s.l)	West	12.8	24.6	26.4	21.3
Kharsu-oak	East	10	9.9	9.1	9.7
(2600 m a.s.l)	West	10.3	5.5	12.3	9.4
Site mean		20.2	21.2	15.5	

Table 2. Net primary production (g·m^{-2}·a^{-1}, dry matter [1]) of herbs in different forest sites.

Forest/Site	Orien-tation	Total net production (g·m^{-2}·a^{-1}, dry matter)		
		Hill base	Hill slope	Hill top
Banj-oak	East	110.0	155.2	53.9
(1980 m a.s.l)	West	305.2	305.1	98.2
Tilonj-oak	East	217.7	121.7	104.8
(2300 m a.s.l)	West	88.6	109.8	151.8
Kharsu-oak	East	96.3	65.2	60.6
(2600 m a.s.l)	West	40.6	30.6	46.8

Similarly, it was found that the biomass decreased significantly with increasing altitude at two different orientations of slope. In

general, sites and stands (hill base, hill slope & hill top) at high elevation exhibit the maximum amount of soil organic carbon and soil organic matter. We found that the site on the west orientation at the high elevation (S3 site) showed higher contents of soil moisture, organic carbon and nitrogen, compared to those at the low elevation (S1 and S2 site) on the east orientation (Fig. 1).

The range of percent allocation of herb species at different forest sites was shown in Table 3 and it was found that percent allocation value in terms of above and below-ground biomass by dominant species varied in different forest sites. The density values showed significant relation with some of the substrate components, such as soil organic carbon and soil moisture but no significant correlations with soil organic matter and soil nitrogen (Table 4).

Across the forests, net primary production (g·m^{-2}·a^{-1}, dry weight) of herb species was the maximum in the Banj-oak forest (hill slope) and minimum (hill top) in the Kharsu-oak forest. Banj-oak forest had the maximum value for net primary production at hill base and slope (Western orientation). Among the sampling sites, a considerable variation in biomass production (below and above-ground) of the total species (8.8 to 227.9 g·m^{-2}, dry weight) was observed. West orientation site exhibits maximum biomass and biomass decreases significantly with increase in altitude and it was found that total production of the herbaceous flora decreased slightly with increasing altitude.

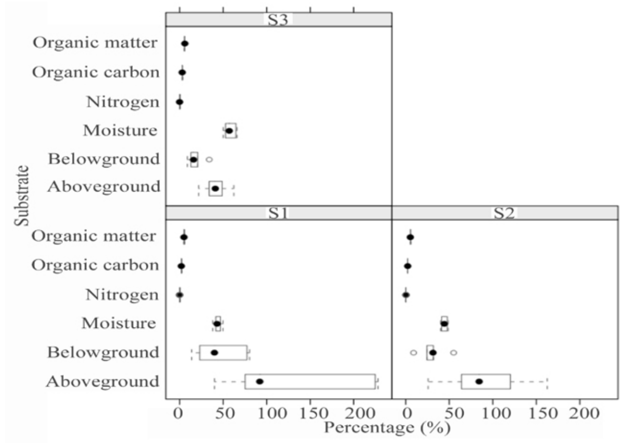

Fig. 1 Percent contribution of substrates in different sites
S1 represents banj-oak at 1980 m a.s.l.; S2 represents tilonj-oak at 2300 m a.s.l.; S3 represents kharsu-oak forest at 2600m a.s.l.

Table 3. Percent allocation of the dominant herb species in Banj-oak forest, Tilonj-oak forest and Kharsu-oak forest

Stand	Part (biomass)	Value	East		West	
			Species	Biomass (g·m^{-2})	Species	Biomass (g·m^{-2})
Banj-oak forest						
Hill base	Below ground	Maximum	*Desmodium multiflorus*	13.32	*Achyranthas bidentata*	16.38
		Minimum	*Geranium wallichianum*	0.03	*Oryzopsis aequiglumis*	0.23
	Aboveground	Maximum	*Pilea umbrosum*	18.64	*Achyranthus bidentata*	21.96
		Minimum	*Anaphalis cinnamonea*	0.04	*Oryzopsis aequiglumis*	0.22
Hill slope	Below ground	Maximum	*Ainsliaea aptera*	25.83	*Achyranthes bidentata*	31.93
		Minimum	*Geranium wallichianum*	0.10	*Arthraxon prinoides*	0.56
	Aboveground	Maximum	*Ainsliaea aptera*	22.95	*Achyranthes bidentata*	32.70
		Minimum	*Nervilea crispate*	0.11	*Ainsliaea latifolia*	0.49
Hill top	Below ground	Maximum	*Potentilla nepalensis*	41.40	*Galium rotundifolium*	39.57
		Minimum	*Oxalis latifolia*	0.14	*Arthraxon prionodes*	0.56
	Aboveground	Maximum	*Viola canescens*	34.18	*Galinsoga ciliata*	11.93
		Minimum	*Plectranthus japonicus*	0.07	*Nervilea crispate*	0.77
Tilonj-oak forest						
Hill base	Below ground	Maximum	*Thalictrum foliolosum*	43.92	*Plectranthus japonicus*	28.10
		Minimum	*Sanicula elata*	0.36	*Justicia simplex*	1.35
	Aboveground	Maximum	*Thalictrum foliolosum*	48.19	*Plectranthus japonicus*	16.46
		Minimum	*Sanicula eleta*	0.30	*Viola canescens*	1.37
Hill slope	Below ground	Maximum	*Roscoae purpurea*	11.39	*Stachys sericea*	21.96
		Minimum	*Viola canescens*	0.88	*Bupleurum tenue*	0.44
	Aboveground	Maximum	*Leucas lanata*	11.73	*Leucas lanata*	18.31
		Minimum	*Viola canescans*	0.58	*Oxalis latifolia*	1.03
Hill top	Below ground	Maximum	*Oryzopsis aequiglumis*	30.33	*Sedum sinuatum*	25.39
		Minimum	*Bupleurum tenue*	0.33	*Fragaria indica*	1.58
	Aboveground	Maximum	*Oryzopsis aequiglumis*	30.33	*Sedum sinuatum*	34.93
		Minimum	*Sanicula elata*	1.86	*Arthraxon priOnodes*	0.96

Continue Table 3

Stand	Part (biomass)	Value	East		West	
			Species	Biomass (g·m^{-2})	Species	Biomass (g·m^{-2})
Kharsu-oak forest						
Hill base	Below ground	Maximum	*Polygonum amplexicaule*	35.68	*Plectranthus striatus*	22.94
		Minimum	*Viola pilosa*	0.16	*Polygonum nepalense*	0.07
	Aboveground	Maximum	*Plectranthus striatus*	37.16	*Plectranthus striatus*	29.61
		Minimum	*Campanula colorata*	0.18	*Epilobium royleanum*	0.32
Hill slope	Below ground	Maximum	*Siegesbeckia orientalis*	21.0	*Plectranthus striatus*	28.96
		Minimum	*Geranium wallichianum*	0.18	*Selinum wallichianum*	0.11
	Aboveground	Maximum	*Plectranthus striatus*	20.0	*Plectranthus striatus*	30.24
		Minimum	*Geranium wallichianum*	0.18	*Selinum wallichianum*	0.09
Hill top	Below ground	Maximum	*Anaphalis busua*	25.57	*Siegesbeckia orientalis*	49.38
		Minimum	*Oxalis latifolia*	0.05	*Torilis japonicus*	0.08
	Aboveground	Maximum	*Siegesbeckia orientalis*	34.73	*Siegesbeckia orientalis*	49.47
		Minimum	*Oxalis latifolia*	0.07	*Torilis japonicus*	0.12

Table 4. Correlation between different parameters

Parameters		Significance level
Moisture	Density	*
Organic carbon	Density	**
Nitrogen	Density	NS
Organic matter	Density	NS
Density	Total biomass	**
Organic carbon	Total biomass	*
Organic matter	Total biomass	*
Diversity	Total biomass	*
Altitude	Moisture	**
Altitude	Organic carbon	**
Altitude	Below ground biomass	*
Altitude	Total biomass	NS
Eastern aspect (altitude)	Total biomass	NS
Western aspect (altitude)	Total biomass	**
Eastern aspect (altitude)	Moisture	*
Western aspect (altitude)	Moisture	*
Eastern aspect (altitude)	Density	**
Western aspect (altitude)	Density	**
Eastern aspect (altitude)	Organic carbon	**
Western aspect (altitude)	Organic carbon	**
Eastern aspect (altitude)	Organic matter	*
Western aspect (altitude)	Organic matter	NS

Notes: Significance level: * $p<0.05$; ** $p<0.01$; NS, not significant.

Discussion

With increase in herbaceous density, above and below-ground biomass increased significantly. Interestingly, plant density and above-ground biomass showed no significant correlations with altitude. But below-ground biomass increased with increasing altitude (Table 4). The net primary production of herb species increases with the decreasing shrub diversity and it might be due to less site-specific competition. A significant correlation was found between herb net primary production and shrub diversity (r=0.730, p<0.01).

The research results obtained by Mountousis et al. (2006) indicated that the geography influences the distribution of precipitation, temperature, moisture, as well as the different kinds of growing vegetation. Generally, eastern part of an area indicates greater moisture than the western part. This result further explains to variation of plant species in different sites. At a global scale, Lieth (1975) also explained the relationship between climatic factors (annual mean temperature, annual precipitation and annual evapo-transpiration) and NPP in logistic function. Brown and Lugo (1982) observed that with increase in precipitation, biomass decreased in tropical forests of humid sites.

We found that soil organic carbon, soil organic matter, soil nitrogen, soil moisture content and above-ground production increased whereas below-ground production decreased with increasing altitude (Fig. 1). In the present study, the above-ground herbaceous production value is similar to that of the mixed and temperate deciduous forests (Duvigneaud 1968). Net primary production generally decreased with increasing altitude in a linear function. Temperature and precipitation, singly or in combination, explained 60%–68% of the net primary production variation with logistic relationships, while the soil organic carbon and total nitrogen variables explained only 21%–46% of the variation with simple linear regressions of log transformed data. Edward and Maston (2001) found that the tropical or subtropical evergreen broad leaves with relatively shorter life span (about 1-3 years) would favour mineral conservation and maintain optimal growth rates by reducing nutrient leaching. The contribution of total net production of herbaceous species in the present study was more or less consistent to the temperate deciduous oak forest (Johnson and Risser 1974) and evergreen oak forest (Negi et al. 1983).

May and Webber (1982) observed that the patterns of ANP and BNP were controlled by water availability, length of growing season and soil stability. The above-ground biomass pro-

duction initially reduced in higher altitudes and later increased with altitude (Mountousis et al. 2006). Since decline in temperature generally occurs at high altitudes largely, the rainfall in the late summer is generally due to returning monsoon. These climatic factors also seem to be responsible for building up greater productivity. According to the results by Satoo (1968), the evergreen broad leaf forests of warm temperate zones are more productive. Mountousis et al. (2006) concluded that above-ground biomass varied among altitudes and aspects. They proved that there was a very significant influence of the combination of altitude and aspect in above-ground biomass production in rangelands in northern Greece. Edward and Maston (2001) found that variation in rainfall had an enough potential to alter pattern of primary productivity and nutrient cycling. In addition, Grubb (1971) stated that structure and productivity of the montane forests in the humid tropics varied with increasing altitude due to the moisture and temperature regime.

The present data indicate that with increasing soil moisture content, density and biomass decrease significantly. The percent contribution by the herbaceous vegetation in terms of above and below-ground biomass varied in sampling stand/forest sites. The net primary production decreases with increasing altitude and varied in different forests. In this study, altitude gradients adversely affect the density. This relation justified that as the altitude increased; the climatic conditions became unfavourable for the survival of the plant species by which the individual number of species also reduced. This is well known fact that plant productivity has linear relationship with plant diversity which is influenced by various factors viz., physical settlement of landscape, geographical area, evolutionary development, environmental variables and soil fertility and humus activity (Zobal 1997; Criddle et al. 2003). An increase in altitude also supported that the net production of herbaceous vegetation varied at different sampling sites. In conclusion, our results suggested that the herb layer respond to soil factors and varied greatly with elevation.

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